NASA TECHNICAL MEMORANDUM

NASA TM X-53131

SEPTEMBER 17, 1964

NASA TM X-53131

ANALYSIS OF CLOSED CIRCUIT TELEVISION AND FIBER OPTICS FOR REMOTE VISUAL CONTROL OF TIG WELDING

by W. A. WALL AND L. K. SWAIM
Manufacturing Engineering Laboratory

GPO PRICE $ ______

OTS PRICE(S) $ ______

Hard copy (HC) $2.00

Microfiche (MF) $0.50

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

FACILITY FORM 602

N65 12018 (ACCESSION NUMBER)

(THRU)

32 (PAGES)

1 (CODE)

TMX 53131 (NASA CR OR TMX OR AD NUMBER)

14 (CATEGORY)

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ABSTRACT

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Two weld viewing systems, closed circuit television and stereo fiber optics, were tested for their relative abilities to transmit weld quality information to the weld operator. These tests were arranged to gather statistical data for comparing the information transmission merits of the two systems. One goal of the project was to determine if the validity of this method of analysis could be established. Data reduction supported the postulation that definite trends could be denoted using this test approach, and results support the belief that both fiber optics and closed circuit television pictures are suitable for remote aluminum welding control.

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W. A. Wall and L. K. Swaim

EXPERIMENTAL ELECTRONIC DEVELOPMENT BRANCH
MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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TECHNICAL MEMORANDUM X-53131

ANALYSIS OF CLOSED CIRCUIT TELEVISION AND FIBER OPTICS FOR REMOTE VISUAL CONTROL OF TIG WELDING

SUMMARY

Two weld viewing systems, closed circuit television and stereo fiber optics, were tested for their relative abilities to transmit weld quality information to the weld operator. These tests were arranged to gather statistical data for comparing the information transmission merits of the two systems. One goal of the project was to determine if the validity of this method of analysis could be established.

Data reduction supported the postulation that definite trends could be denoted using this test approach, and results support the belief that both fiber optics and closed circuit television pictures are suitable for remote aluminum welding control. Extensive analysis of the test samples indicates that the weld operator never failed to correct a maladjusted weld setting using television and fiber optic monitoring. Further, it is concluded that, from strictly an operational viewpoint, closed circuit television is superior to fiber optics as a means of image magnification and ease of viewing.

INTRODUCTION

Engineering Project 3035 was initiated to develop apparatus for remote viewing of aluminum welding. Two distinctly different systems of remote viewinh have evolved from this engineering project in the form of a black and white closed circuit television system and a fiber optic system which features stereo depth perception effect and color transmission. Because of the difficulty of describing, in words, the total information available from each device, it was decided that a series of tests should be conducted to more fully evaluate and compare the two viewing systems. The basis of these tests was to attempt to determine by statistical methods how dependably a weld operator could control the TIG process when relying entirely upon remote viewing devices to monitor the weld. Since the two viewing systems, CCTV and fiber optics, have totally different attributes, it was felt that one system might prove vastly superior to the other. On the other hand, it was possible that both systems were of about equal

picture quality and the selection of a viewing system for a particular job would depend principally on physical and economic considerations.

TEST APPARATUS

1. The test welding apparatus consisted of a Linde HWN-2 controller and manipulator for TIG welding of aluminum alloy 2219-T87. The welding was performed without joint backup, Figure 1, to simulate most SATURN SI-C welding conditions. Welding current and voltage were monitored with a clamp-on DC ammeter and a 2 percent accurate Triplett voltmeter. Welding speed was read from a calibrated meter on the Linde travel governor. Since only relative values were of interest, this instrumentation was considered sufficient.

2. The closed circuit television equipment consisted of the following components:

a. Camera, Hallamore Model CC420, with 650 horizontal line resolution

b. Monitor and Camera Control, Hallamore Model MR17BR

c. Vidicon, RCA No. 7038 (See Figure 2 for characteristic curve)

d. Lens, 4 inch, F 2.5

e. Ambient Light Source, Sylvania Sun Gun, 3400 degrees K light temperature, (See Figure 3)

f. Filter, interference, (See Figure 4 for characteristics)

3. The fiber optic system, Figure 5, is a 9-foot, stereo, 8 x 10 millimeter system with image enhancement and adjustable polaroid light filters. This system was built by OPTO Mechanisms, Inc., in compliance with R-ME specification MR&T SK 392, REV A, and is known as OPTO Mechanisms Model 565 with image enhancement.

METHOD OF TESTING

In order to get meaningful statistical data from this type of test, the testing was limited to the variation of one weld parameter at a time while all other weld parameters were held constant. The theory was to let the operator do his best to correct a maladjusted weld setting while monitoring it remotely,

and determine, by tensile test, X-ray, and penetration measurements, the operator's degree of success. The principle weld parameters affected were:

1. Weld voltage

2. Weld Current

3. Weld speed

On a typical test, the test panels were tack welded at both ends, lined up with the torch, and the operator would initiate weld start with known weld parameter settings and full penetration. Satisfied with the weld, the operator would change from direct visual monitoring to either CCTV, Figure 1 , or fiber optics, Figure 5, for remote viewing. When the sample was approximately one-third finished, a second party, not the weld operator, would change one weld parameter approximately 10 percent, or more, and the weld operator would then attempt to adjust the weld, as nearly as possible, to the initial conditions. The operator was told which parameter had been changed, but he was not allowed to know the amount of change except through his remote visual monitor. Weld correction could not be accomplished instantaneously because large weld parameter changes made a difference in the heat pattern, and the weld had to be stabilized before the adjustment was considered complete. Each test panel was marked to indicate where the parameter change took place and when the weld operator was satisfied with his correction. Therefore, there were three principle conditions on each weld sample:

1. The beginning with known weld parameters and penetration

2. The middle portion subjected to change

3. The final condition after operator correction

Each test panel was X-rayed for porosity and visually inspected for loss of penetration. After X-ray, one or more test specimens from each of the starts, the maladjusted, and the corrected portion of the test panel, was cut out for tensile test. The results of the tensile tests are tabulated in Appendix A and graphically illustrated in Figures 6 - 12. It should be noted that these tests were limited to 1/4-inch and 3/8-inch materials, and the tests were stagge. l such that a different weld parameter was changed on each successive test panel. Of special interest was an extra-curricula test, Figure 12, conducted after the scheduled tests were completed. This time, two parameters, current and travel, were changed simultaneously, but the operator was not told what had been changed.

The weld operator made a remarkable recovery! On panel No. 1, he actually increased the weld strength during correction, and on panel No. 2, he reproduced the original good weld properties with a high degree of accuracy and skill. The viewing medium was CCTV. These two tests, more than anything else, tested the practicality of remote viewing equipment.

DISCUSSION

The optical interference type coated filter with transmission characteristics as shown in Figure 4, allowed the work to be performed with the best CCTV weld picture currently attainable. The picture quality stems from the use of a powerful sun-gun light source to illuminate the picture area in conjunction with the excellent visible light transmission characteristics of the interference filter. The remainder of the CCTV equipment is standard television and optical hardware. Of importance is the fact that the angle of the reflected light rays from the ambient light source is critical because of the interference filter. One light source, as Light A Figure 13, must be located so that it is in line with the TV camera and of about the same angle of incidence with respect to the work. The ambient rays should leave the light source, strike the aluminum surface at some angle of incidence, and leave the work at approximately the same angle to enter the TV camera. A second light, Light B Figure 13, can be used to illuminate the front of the torch and to eliminate shadows.

Standard fiber optic cables have excellent weld picture transmission qualities. Due to ambient lighting, the picture transmitted to the weld operator's eyes is much better than would be expected through a standard welder's green filter. The ambient lighting required for fiber optics is not as critical as it is for the above described CCTV setup, and a wide latitude of adjustment can produce about the same effect.

Lighting is important because the operator uses the side of the weld to judge the correct penetration and heat. A smooth side means no undercut; whereas, a rough side means too much penetration and the heat must be decreased. The bead width allows the operator to maintain correct voltage and speed. When using CCTV, the weld operator has a definite advantage in judging the roughness of the side of the weld because of the high magnification, 6X to 10X, of the CCTV system. Minute variations of the tungsten torch electrode are easily detectable on CCTV. The fiber optic cable system used for these tests has a magnification of about 1X when viewing an object 12 inches from the image lens.

Of primary importance is the data and findings of this experiment with regard to weld quality and controllability. The bar graphs, Figures 6 - 12, comprise most of the "hard" data gathered during these tests. There are three bars for each test panel. The bar on the left indicates the ultimate weld strength of the initial weld condition. The bar in the center shows the change in weld strength with a change in weld setting, and the bar on the right indicates the final weld strength after correction.

The test panels were run consecutively with no attempt made to eliminate or throw out any test panels. The panel numbers do not appear in numerical order on the graphs because a different parameter was changed on each successive panel. Good X-ray quality was obtained throughout the range of the test except during periods of maladjustment. Loss of penetration is noted on the bar graphs in all cases where detected. Although not absolutely conclusive, a study of the bar graphs of Figures 6 - 12 indicates that:

1. Both fiber optics and CCTV make acceptable tools to remotely view and control welds

2. Neither mode of remote viewing can be termed vastly superior to the other

3. Economic and practical considerations would prevail whenever a system was considered for remote viewing.

The authors were both surprised and pleased with the degree of control a weld operator could exert when using only remote viewing apparatus. The operator who conducted these tests felt confident that he could control the weld after only a day's practice, and most of that day was spent in becoming familiar with the welding apparatus. Five days had originally been allocated on the test schedule for the operator to become accustomed to remote viewing. Of particular interest are the bar graphs of Figure 12 because they indicate the degree of control obtainable via a remote CCTV monitor. Improvement should be concentrated on the refinement of television apparatus and optics to reduce the amount, cost, and size of the monitoring equipment, and to improve picture resolution and information when practical.

CONCLUSIONS

Data gathered during this series of tests shows that both Closed Circuit Television and fiber optics viewing produce about equal picture quality with CCTV having a magnification advantage, and fiber optics a color edge. The operator can use

this picture information to control his weld rather than simply watch because of the vastly improved CCTV picture quality. Although there is not enough statistical data to prove it, the trends clearly visible in these tests indicate that stereo, or depth perception, is not required for welding control of this kind. In addition, CCTV would normally be preferred from an economic and utility point of view if the operator-to-weld distance exceeds 9 or 10 feet, or if the weld must be monitored for extended periods of time. Operator training time would not be a factor, based on our experience.

In conclusion, it is thought that these tests are significant because of the strong trend to prove that not only weld monitoring but also weld control can be reliably achieved through CCTV and fiber optics.

RECOMMENDATIONS

It is recommended that at least one experimental weld fixture (Bldg. 4728) be equipped with a CCTV camera and monitor for weld study purposes. Extreme close-ups with magnifications of 20X to 30X might aid in the study and in the causes of porosity.

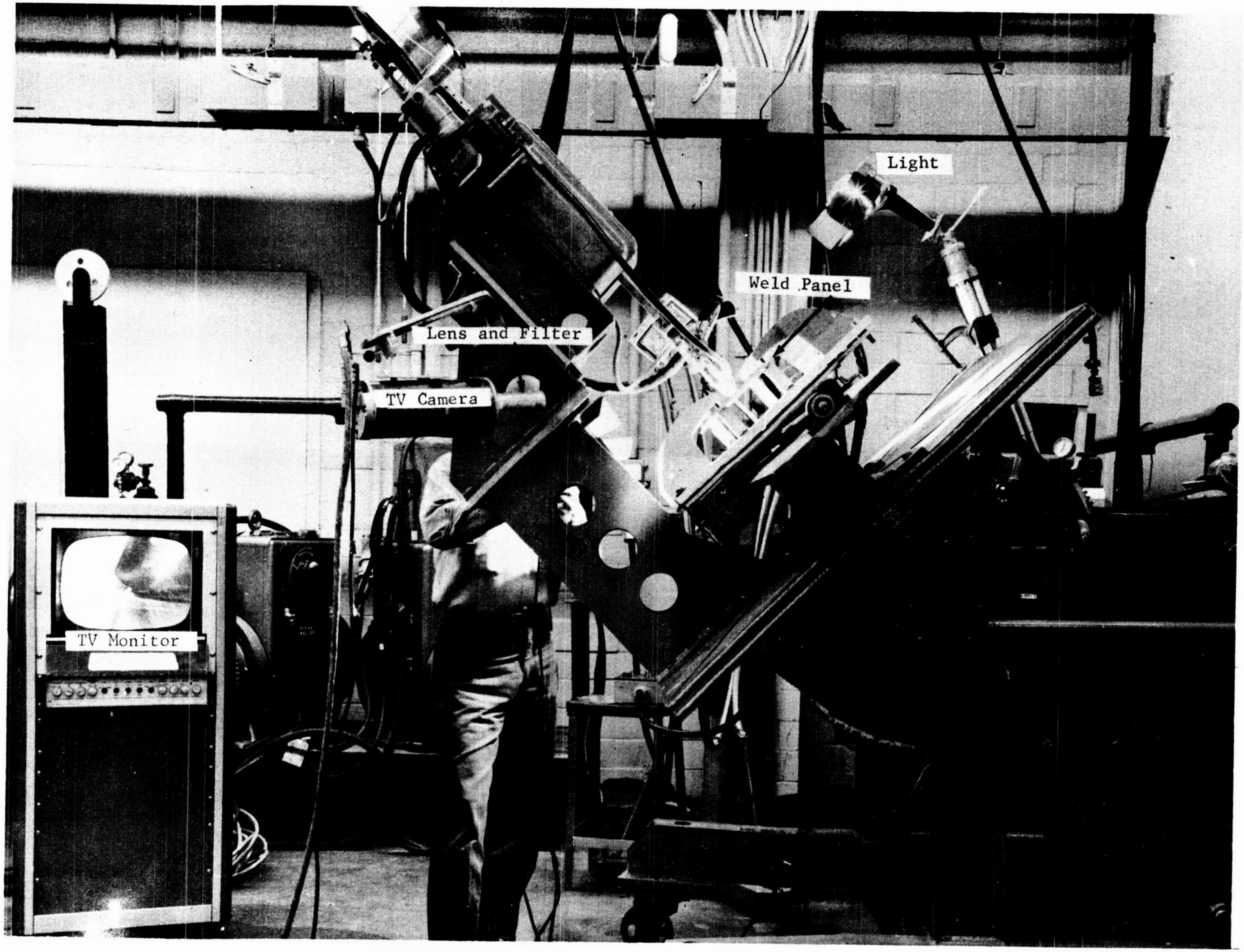


FIGURE 1. CLOSED CIRCUIT TELEVISION TEST SETUP

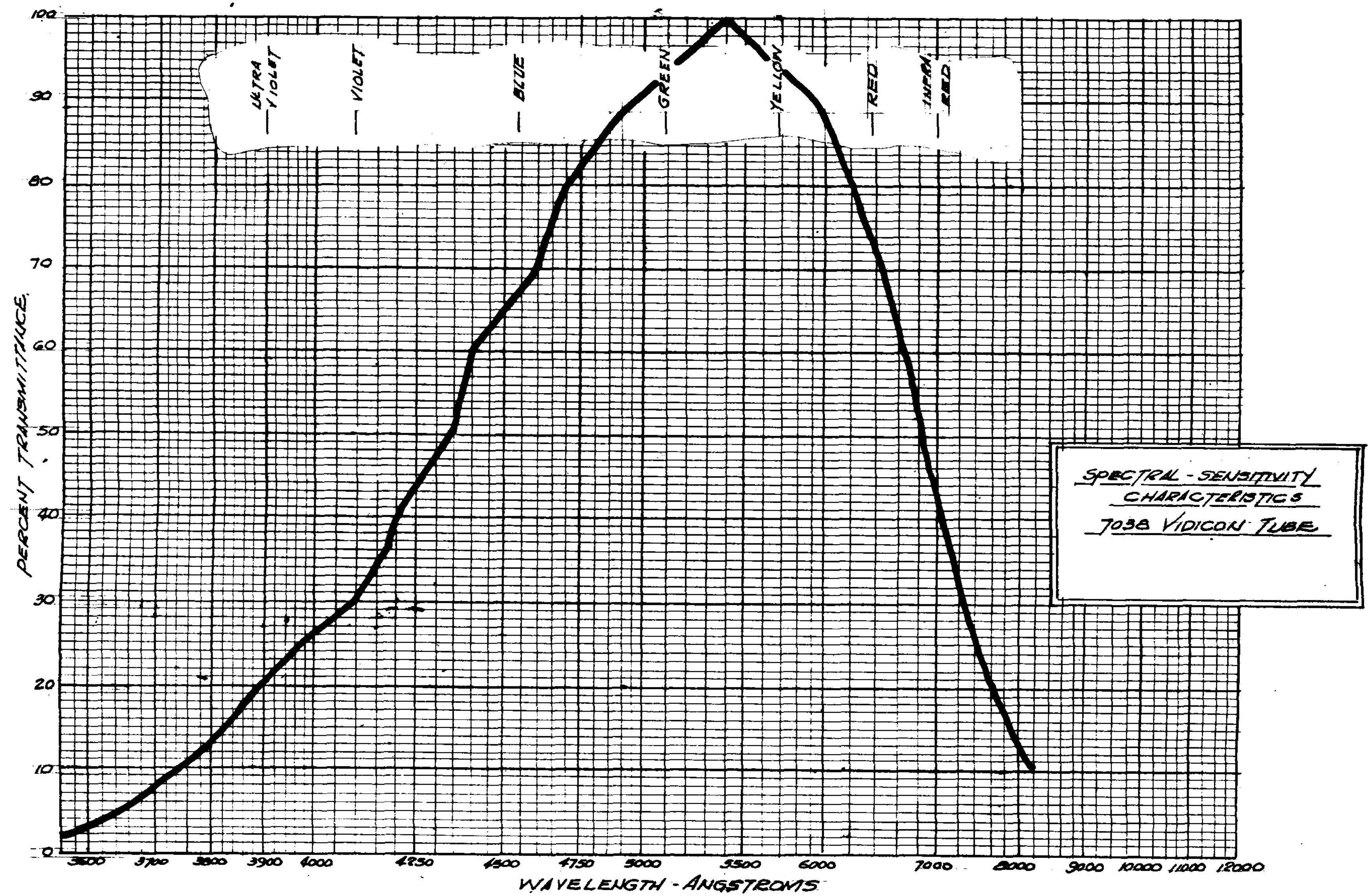


FIGURE 2. SPECTRAL SENSITIVITY CHARACTERISTICS 7038 VIDICON TUBE

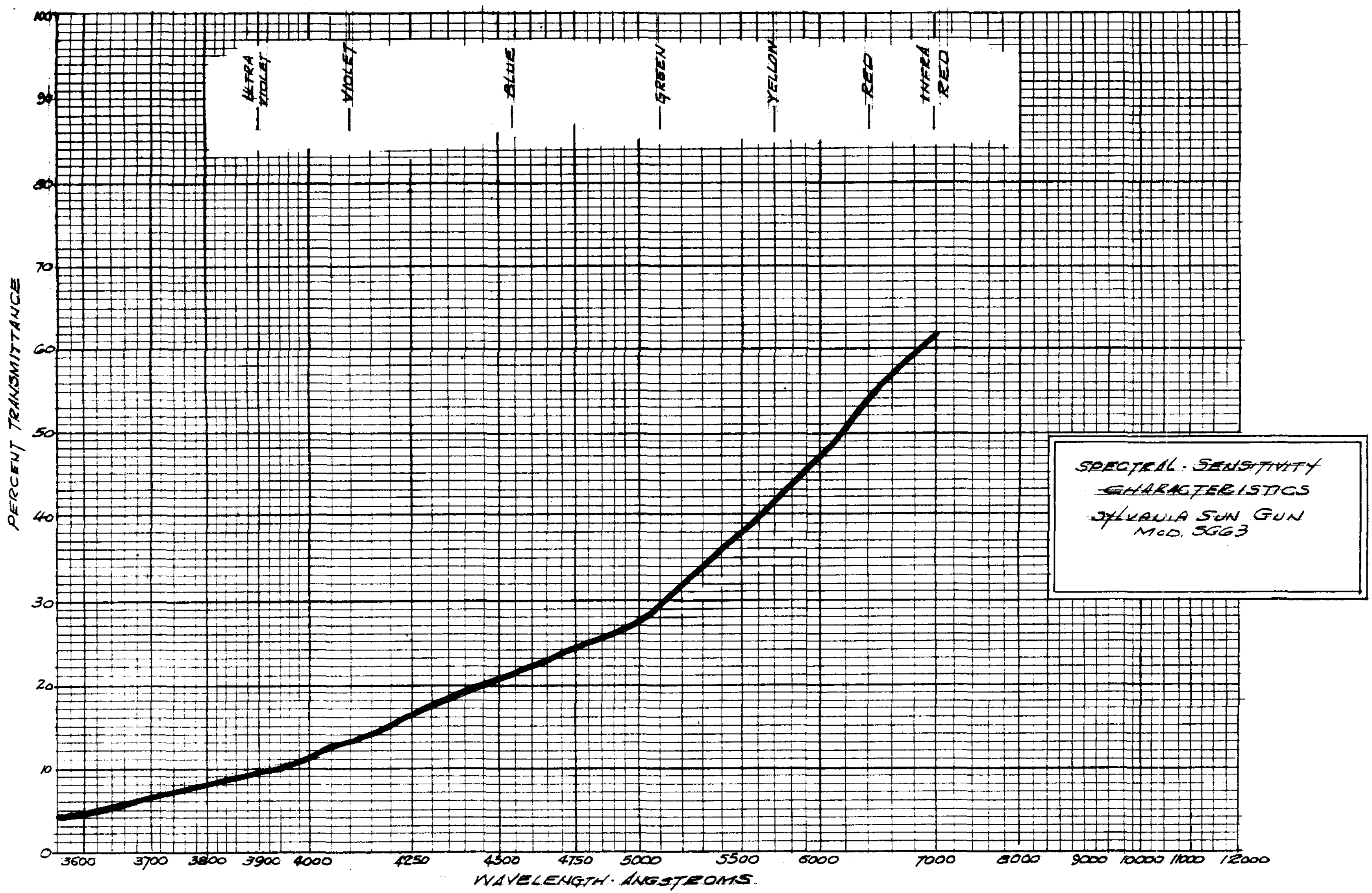


FIGURE 3. SPECTRAL SENSITIVITY CHARACTERISTICS SYLVANIA SUN GUN MODEL SG63

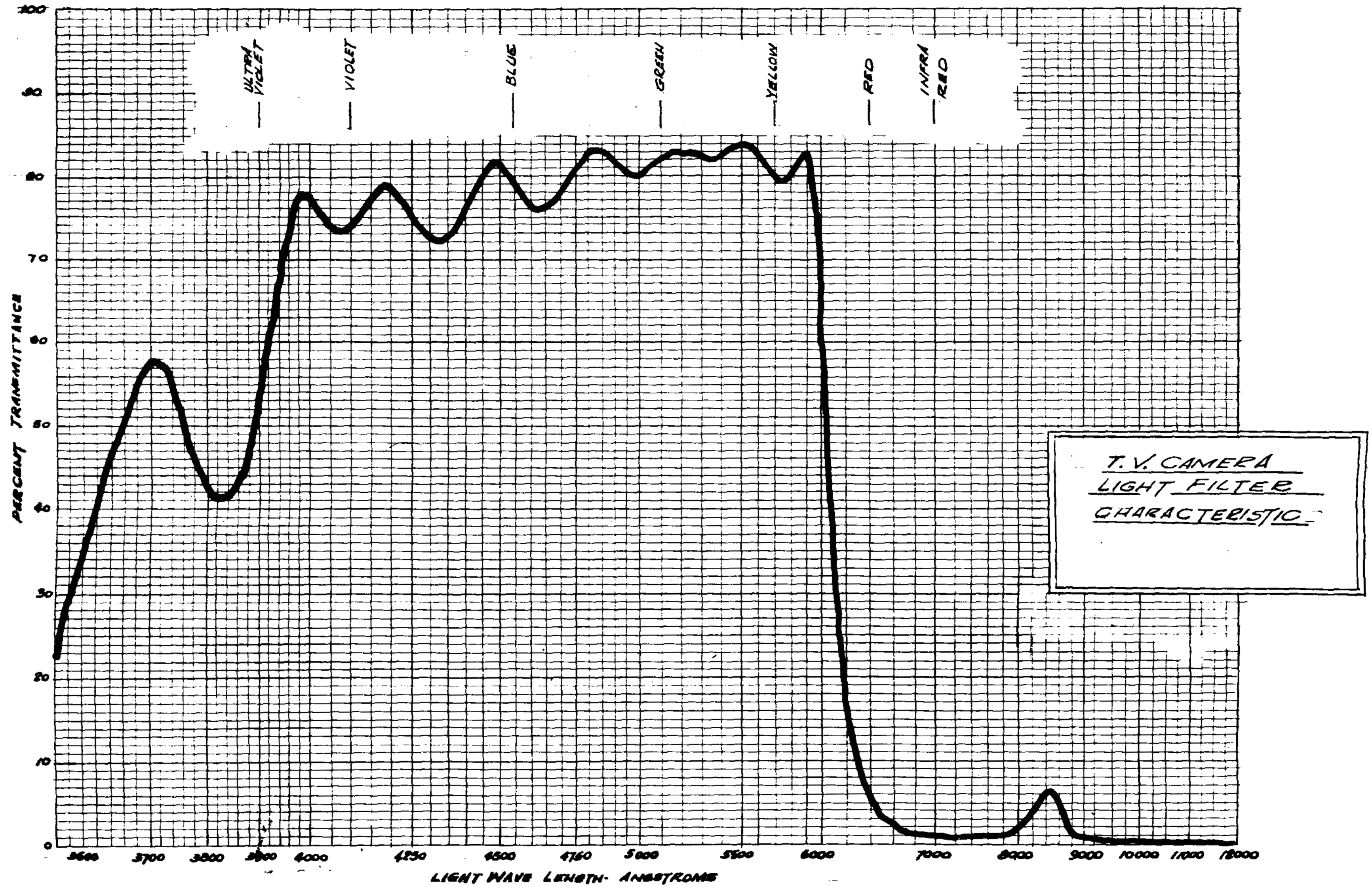


FIGURE 4. TV CAMERA LIGHT FILTER CHARACTERISTIC

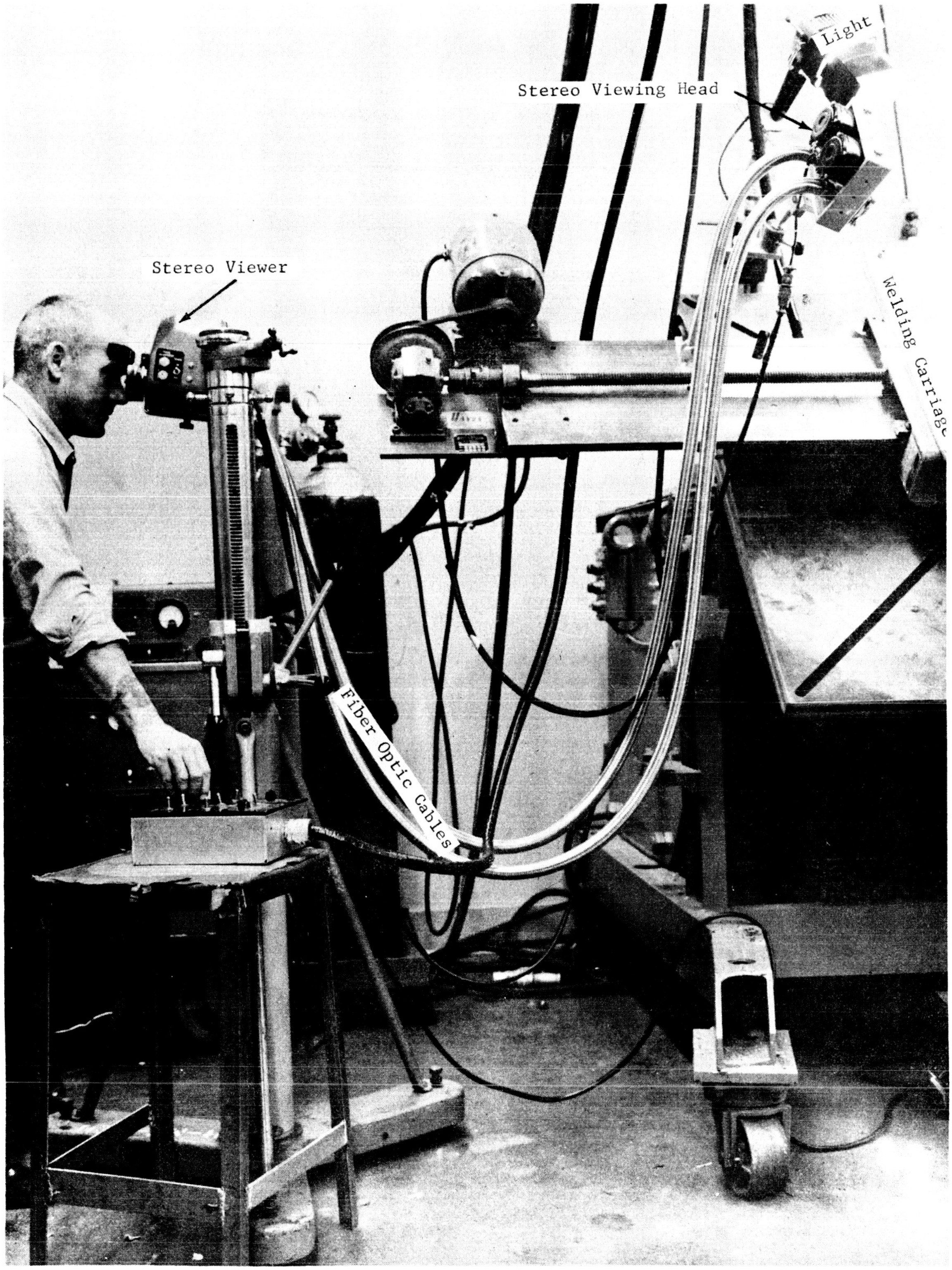


FIGURE 5. STEREO FIBER OPTICS TEST SETUP

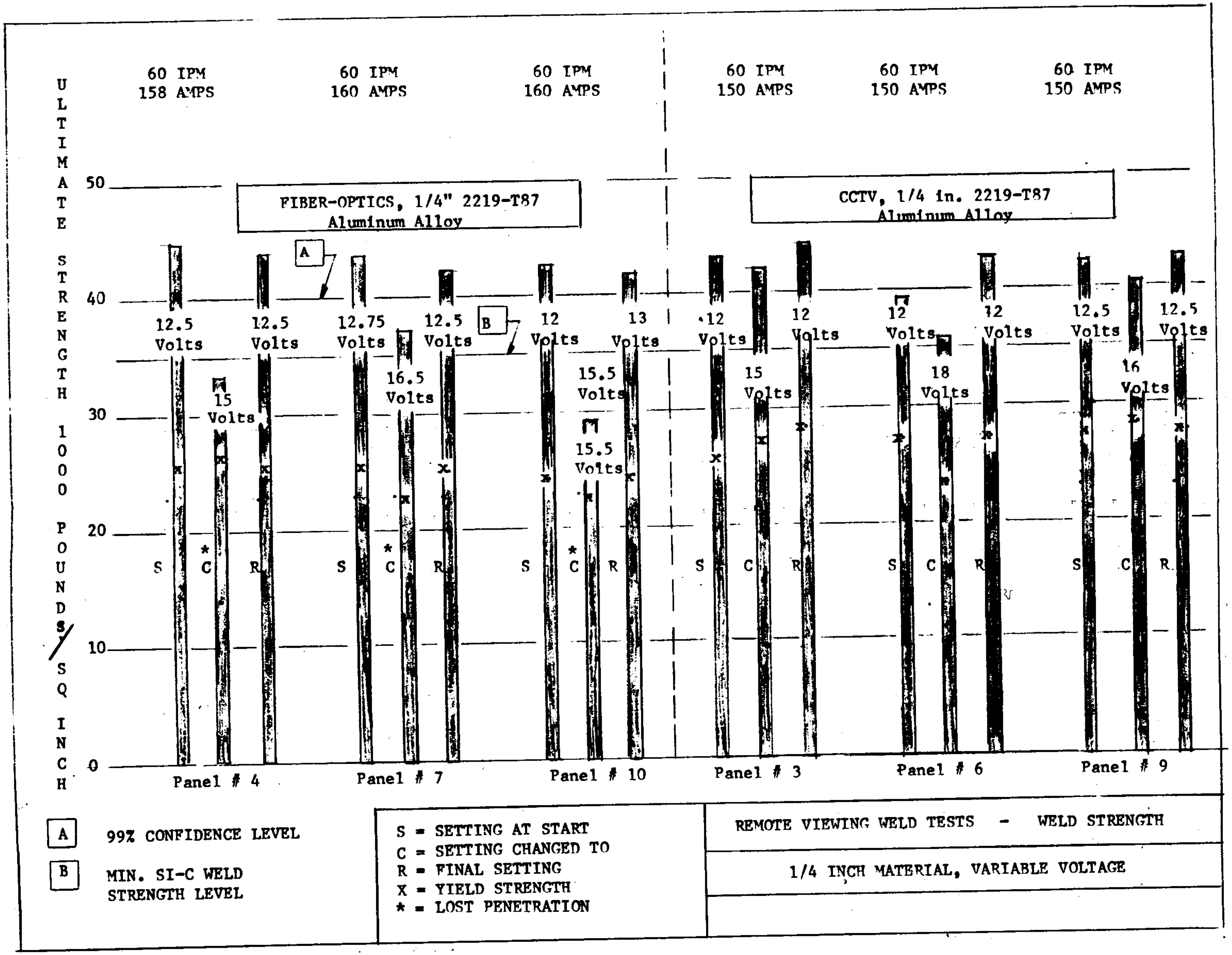


FIGURE 6. REMOTE VIEWING WELD TESTS, TENSILE STRENGTH, 1/4 INCH MATERIAL, VARIABLE CURRENT

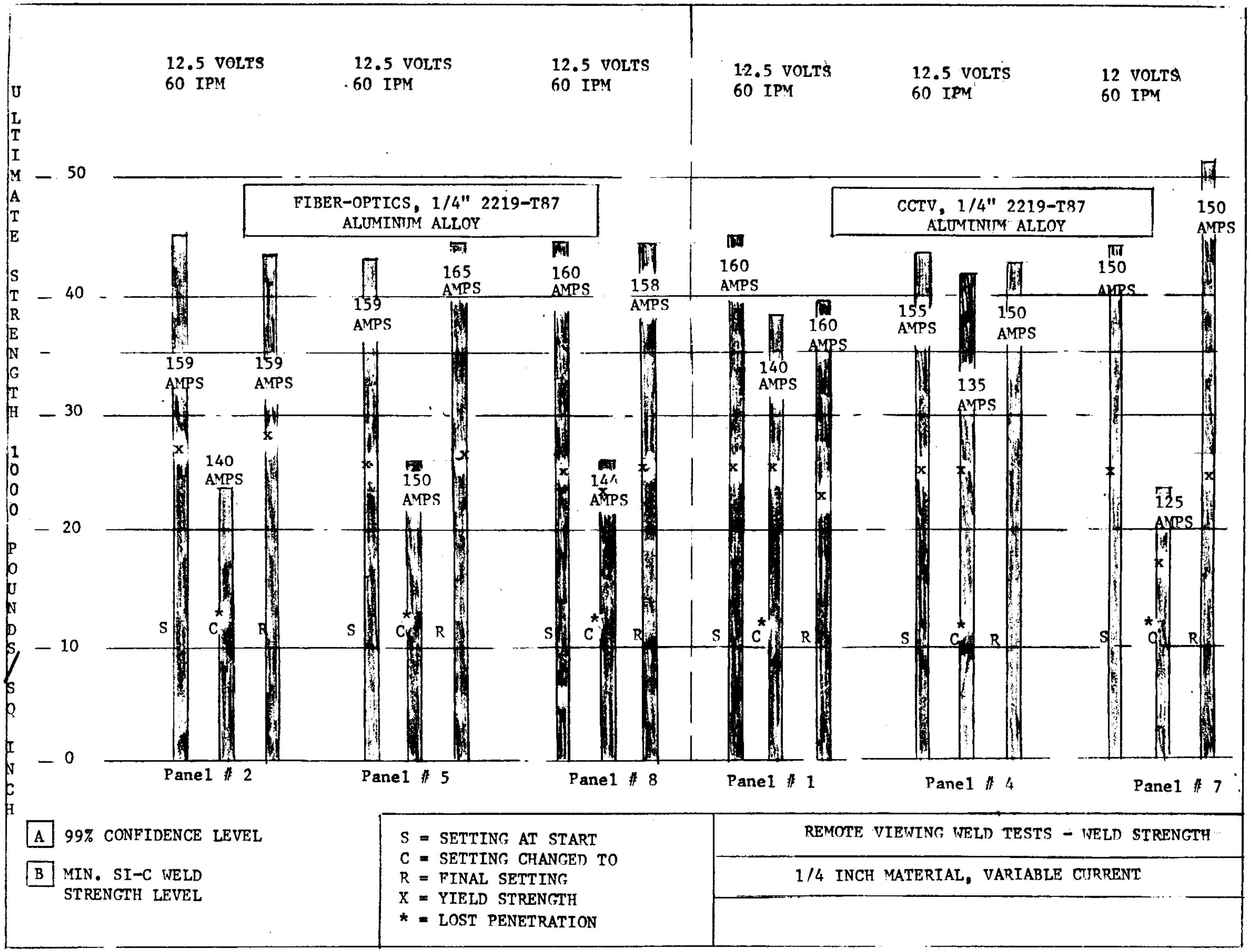


FIGURE 7. REMOTE VIEWING WELD TESTS, 1/4 INCH MATERIAL, VARIABLE CURRENT

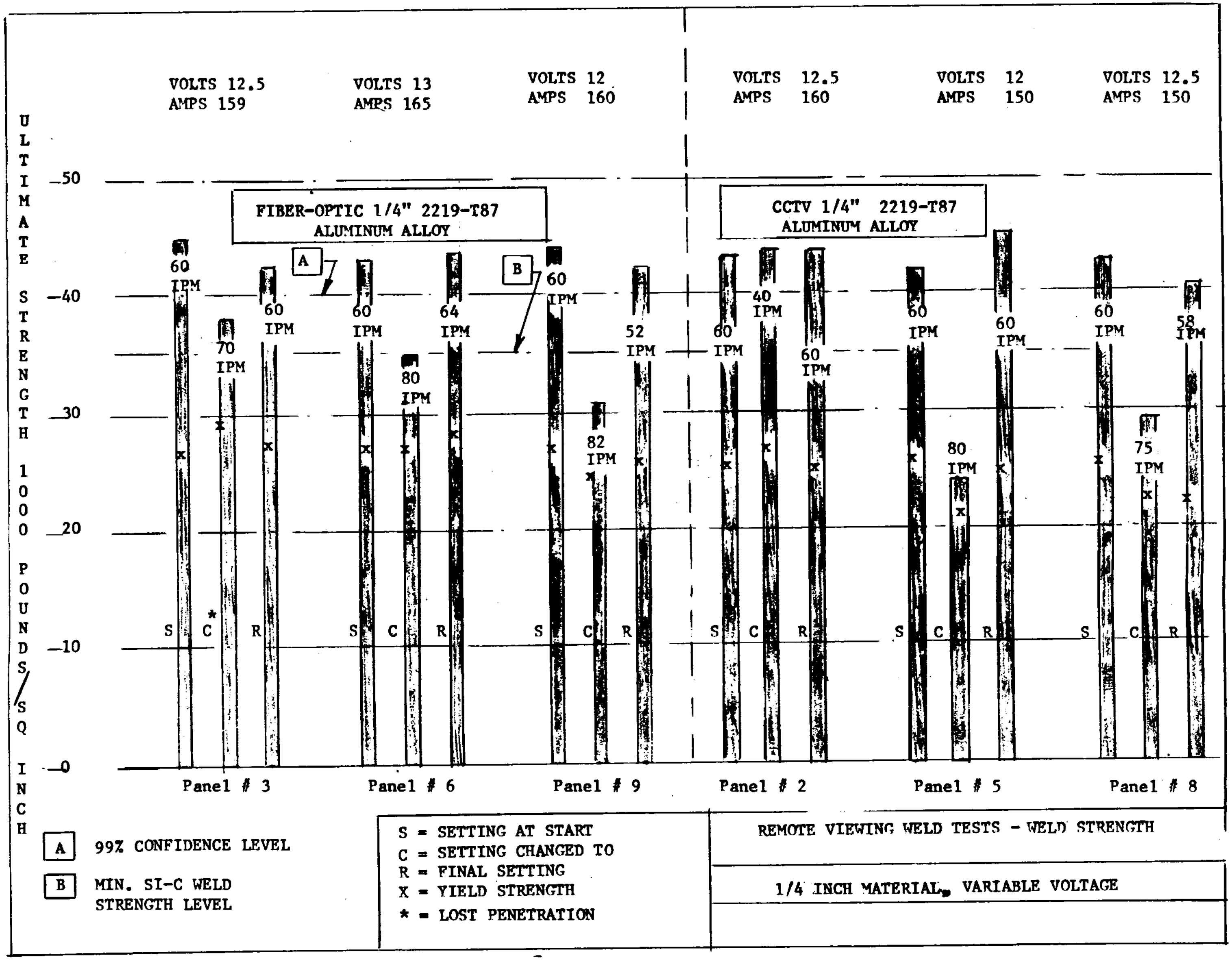


FIGURE 8. REMOTE VIEWING WELD TESTS, 1/4 INCH MATERIAL, VARIABLE CURRENT

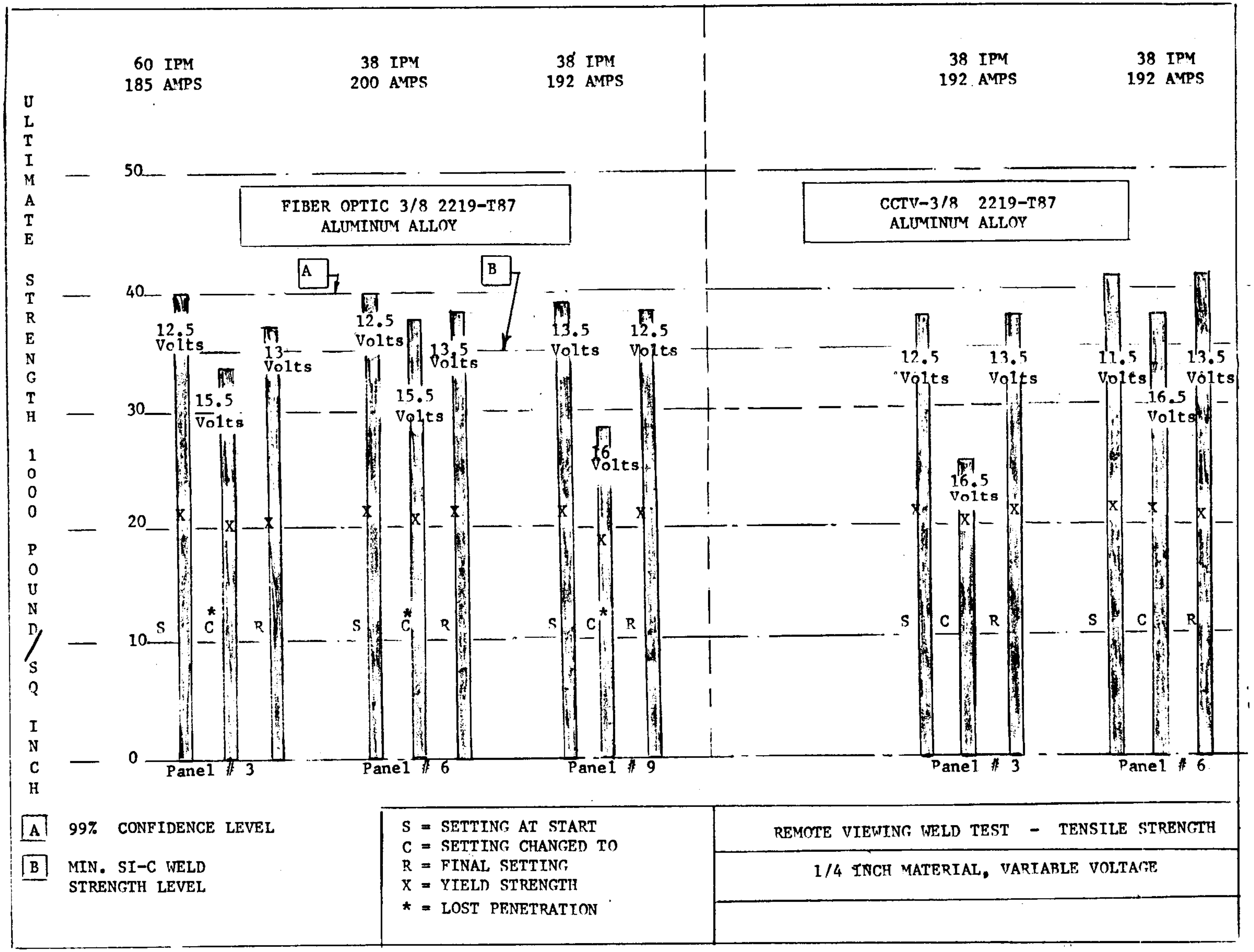


FIGURE 9. REMOTE VIEWING WELD TESTS, 3/8 INCH MATERIAL, VARIABLE VOLTAGE

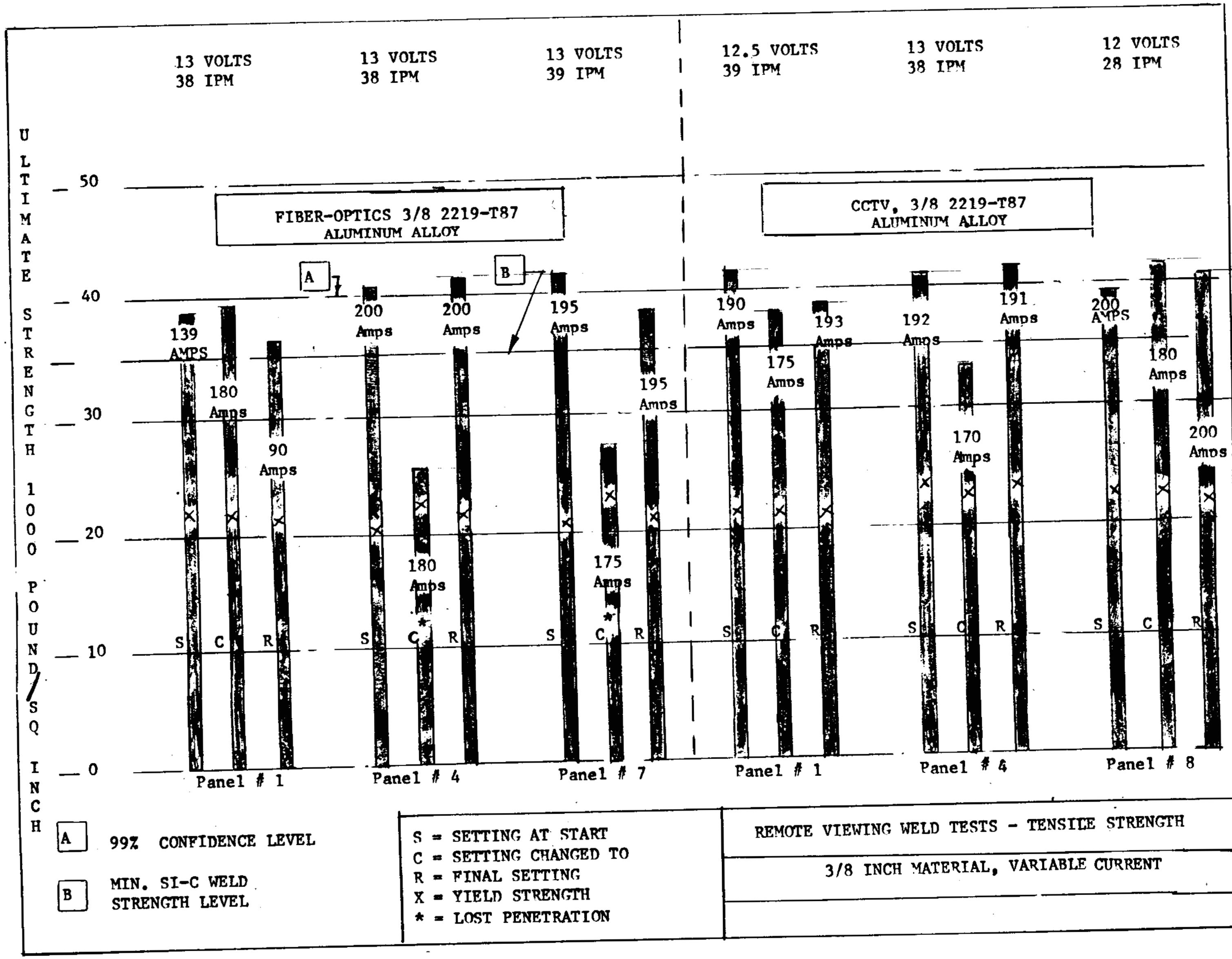


FIGURE 10. VIEWING WELD TESTS, 3/8 INCH MATERIAL, VARIABLE CURRENT

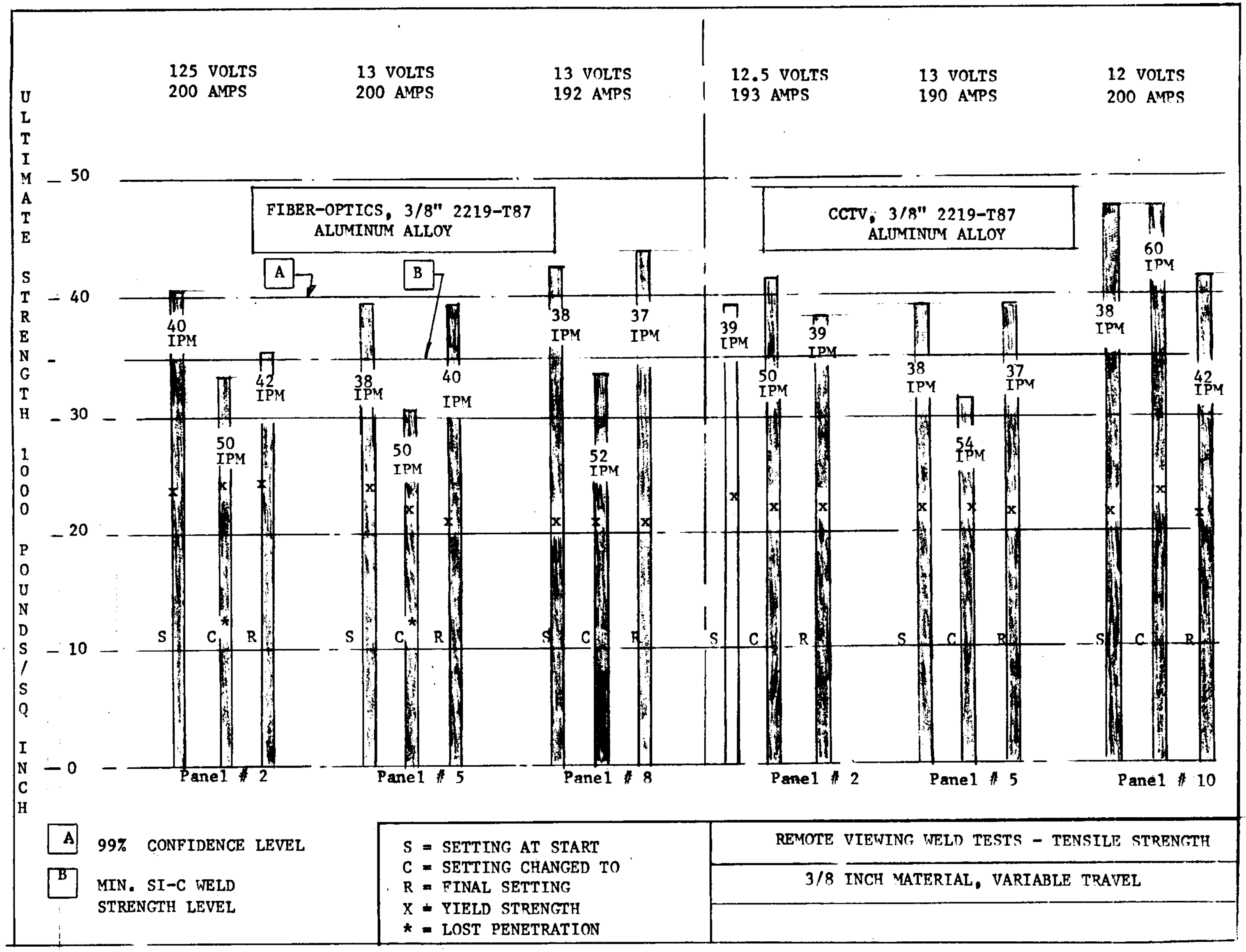


FIGURE 11. REMOTE VIEWING WELD TESTS, 3/8 INCH MATERIAL, VARIABLE TRAVEL SPEED

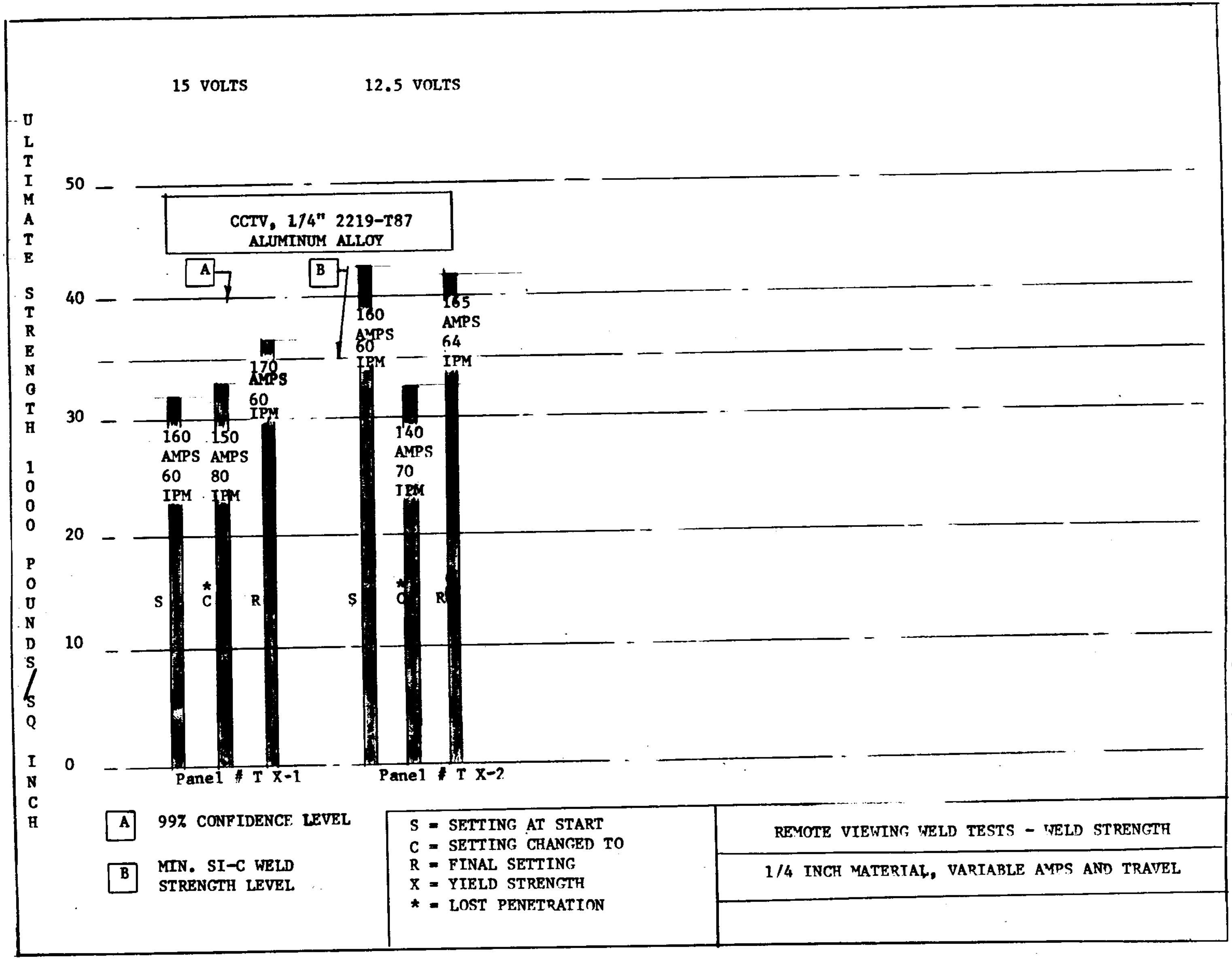
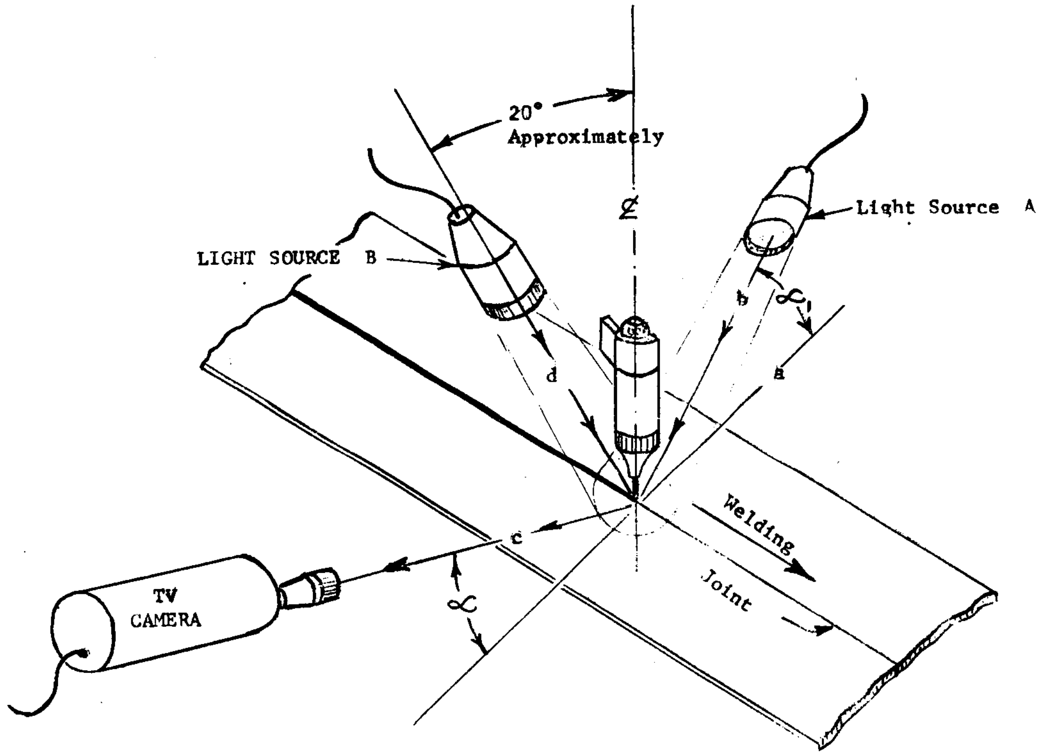


FIGURE 12. REMOTE VIEWING WELD TEST, 1/4 INCH MATERIAL, VARIABLE CURRENT AND TRAVEL SPEED



Notes:

1. $\angle ab = \alpha_1 \approx \angle ac = \alpha$

2. Lines a, b, c, and ℄ torch are all approximately in the same plane.

FIGURE 13. LIGHTING CRITERIA FOR TV CAMERA WITH INTERFERENCE FILTER

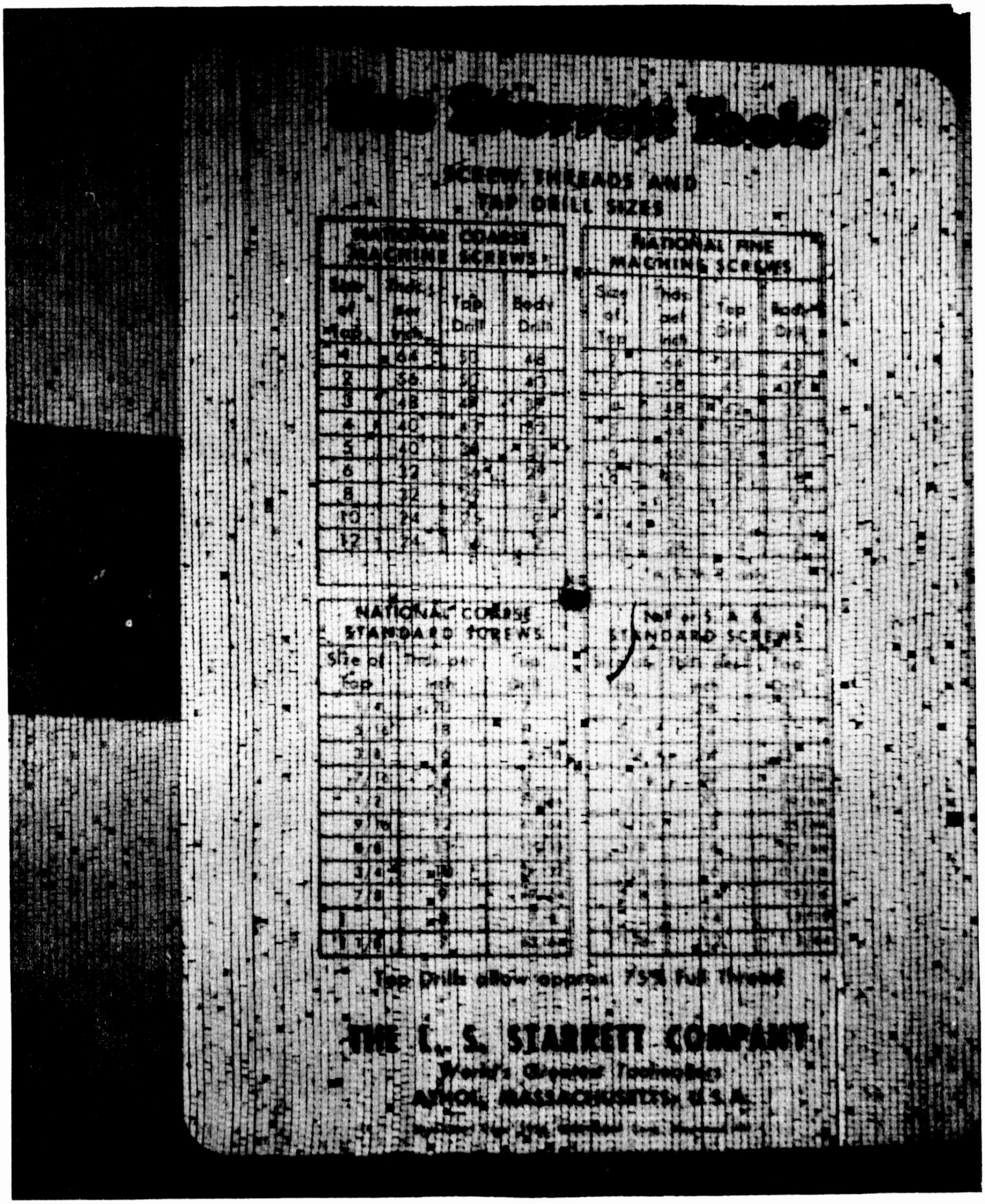
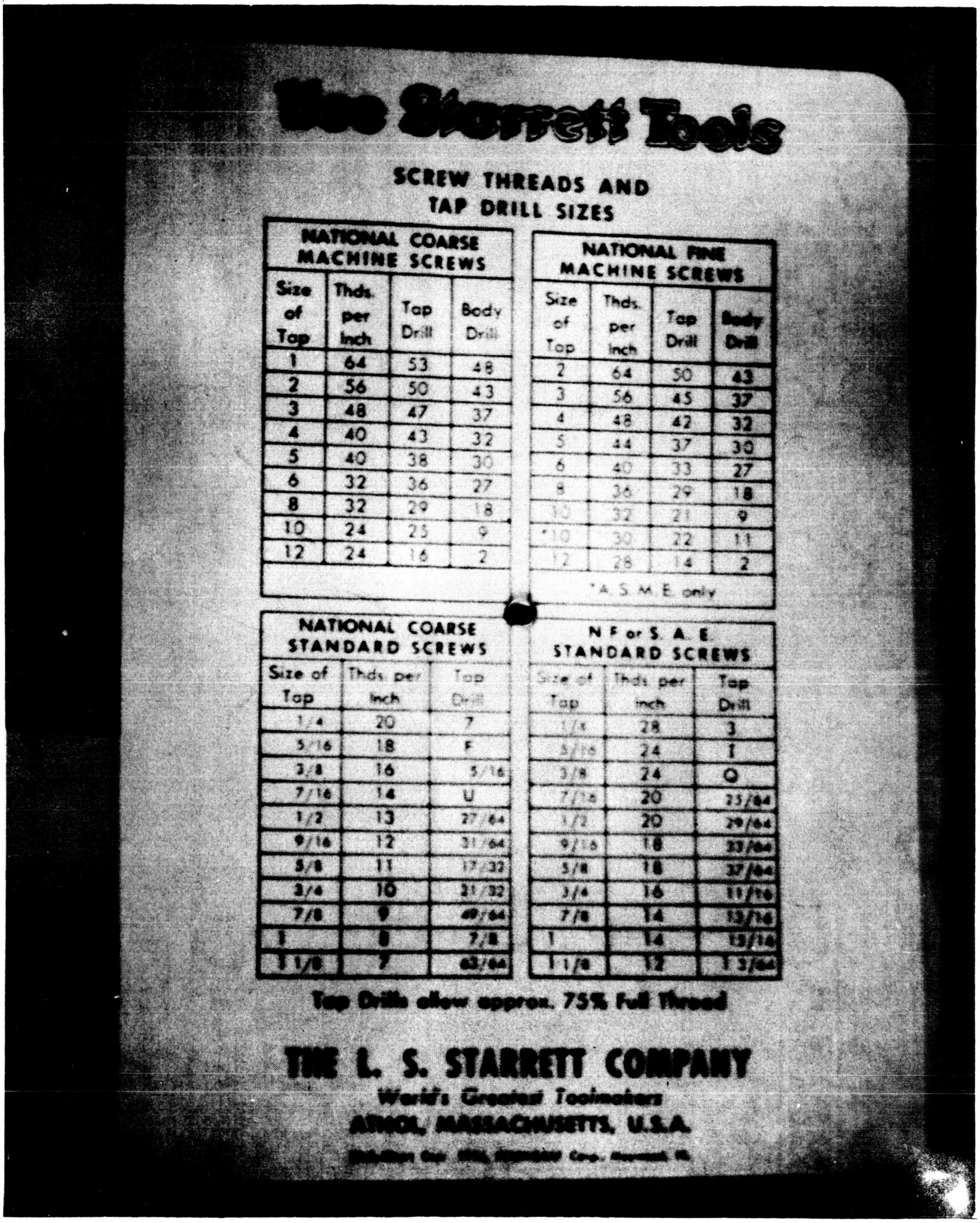


FIGURE 14. MACHINISTS CHART AS SEEN THROUGH FIBER OPTICS WITHOUT IMAGE ENHANCEMENT



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NATIONAL COARSE MACHINE SCREWS

Size of Tap	Thds. per Inch	Tap Drill	Body Drill
1	64	53	48
2	56	50	43
3	48	47	37
4	40	43	32
5	40	38	30
6	32	36	27
8	32	29	18
10	24	25	9
12	24	16	2

NATIONAL FINE MACHINE SCREWS

Size of Tap	Thds. per Inch	Tap Drill	Body Drill
2	64	50	43
3	56	45	37
4	48	42	32
5	44	37	30
6	40	33	27
8	36	29	18
10	32	21	9
*10	30	22	11
12	28	14	2

*A. S. M. E. only

NATIONAL COARSE STANDARD SCREWS

Size of Tap	Thds. per Inch	Tap Drill
1/4	20	7
5/16	18	F
3/8	16	5/16
7/16	14	U
1/2	13	27/64
9/16	12	31/64
5/8	11	17/32
3/4	10	21/32
7/8	9	49/64
1	8	7/8
1 1/8	7	63/64

N F or S. A. E. STANDARD SCREWS

Size of Tap	Thds. per Inch	Tap Drill
1/4	28	3
5/16	24	I
3/8	24	Q
7/16	20	25/64
1/2	20	29/64
9/16	18	33/64
5/8	18	37/64
3/4	16	11/16
7/8	14	13/16
1	14	15/16
1 1/8	12	1 3/64

Tap Drills allow approx. 75% Full Thread

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FIGURE 15. MACHINISTS CHART AS SEEN THROUGH FIBER OPTICS WITH IMAGE ENHANCEMENT

APPENDIX A CONSTANT CURRENT AND TRAVEL SPEED

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	SPECIMEN SIZE	VARIABLE VOLTAGE	COMMENTS	SPECIMEN BROKE
TV	43,030	T3-1	1.503 x .252	12		Fusion Line
TV	42,140	T3-2	1.503 x .251	15		Weld
TV	43,730	T3-3	1.503 x .251	12		Fusion Line
TV	36,190	T6-1	1.503 x .250	12		Fusion Line
TV	38,580	T6-2	1.503 x .250	18		Weld
TV	42,610	T6-3	1.502 x .250	12		Fusion Line
TV	42,000	T9-1	1.501 x .249	12.5		Fusion Line
TV	40,300	T9-2	1.501 x .248	16		Fusion Line
TV	41,640	T9-3	1.501 x .248	12.5		Fusion Line
TV	39,020	T3-1	1.502 x .360	12.5		Fusion Line
TV	34,680	T3-2	1.502 x .359	15		Weld
TV	38,990	T3-3	1.503 x .360	12.5		Fusion Line
TV	40,310	T6-1	1.502 x .370	11.5		Fusion Line
TV	40, 350	T6-2	1.502 x .368	16.5		Fusion Line and Weld
TV	39,340	T6-3	1.502 x .369	12.5		Fusion Line

Sheet 1 of 7

APPENDIX A CONSTANT CURRENT AND TRAVEL SPEED

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	SPECIMEN SIZE	VARIABLE VOLTAGE	COMMENTS	SPECIMEN BROKE
FO *	44,730	F4-1	1.498 x .250	12.5		Fusion Line
FO	33,890	F4-2	1.498 x .251	15	Lack of Penetration	Weld
FO	43,700	F4-3	1.498 x .249	12.5		Fusion Line
FO	43,560	F7-1	1.500 x .251	12.75		Fusion Line
FO	35,860	F7-2	1.500 x .251	16.5	Lack of Penetration	Weld Fusion
FO	42,000	F7-3	1.499 x .251	12.5		Fusion Line
FO	42,860	F10-1	1.499 x .249	12		Fusion Line
FO	29,320	F10-2	1.499 x .248	15.5	Lack of Penetration	Weld
FO	41,700	F10-3	1.500 x .251	13		Fusion Line
FO	40,640	F3-1	1.502 x .360	1.25		Fusion Line
FO	37,050	F3-2	1.502 x .363	15.5	Lack of Penetration	Fusion Line and Weld
FO	40,690	F3-3	1.502 x .360	13		Fusion Line
FO	41.640	F6-1	1.501 x .368	12.5		Fusion Line
FO	36,450	F6-2	1.502 x .369	15.5		Fusion Line and Weld
FO	37,990	F6-3	1.501 x .370	13.5		Fusion Line
FO	38,970	F9-1	1.501 x .359	13.5		Fusion Line
FO	28,520	F9-2	1.501 x .362	16		Fusion Line
FO	37,540	F9-3	1.501 x .362	12.5		Fusion Line

* Fiber Optics

Sheet 2 of 7

APPENDIX A CONSTANT VOLTAGE AND TRAVEL SPEED

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	SPECIMEN SIZE	VARIABLE AMPS	COMMENTS	SPECIMEN BROKE
TV	45,000	T1-1	1.503 x .244	160		Weld
TV	38,450	T-12	1.503 x .244	140	Lack of Penetration	Weld
TV	39,540	T1-3	1.503 x .244	160		Fusion Line
TV	43,620	T4-1	1.501 x .252	155		Fusion Line
TV	41,880	T4-2	1.503 x .251	135	Lack of Penetration	Fusion Line
TV	42,160	T4-3	1.499 x .250	150		Fusion Line
TV	43,830	T7-1	1.503 x .249	150		Weld
TV	23,440	T7-2	1.502 x .250	125	Lack of Penetration	Weld
TV	52,270	T7-3	1.502 x .250	150		Weld
* FO	44,990	F2-1	1.498 x .250	159		Fusion Line
FO	23,740	F2-2	1.501 x .247	140	Lack of Penetration	
FO	43,390	F2-3	1.501 x .248	159		Fusion Line
FO	42,930	F5-1	1.499 x .251	159		Weld
FO	26,070	F5-2	1.500 x .253	150	Lack of Penetration	Weld
FO	43,860	F5-3	1.499 x .251	165		Fusion Line
FO	43,930	F8-1	1.499 x .249	160		Fusion Line
FO	26,510	F8-2	1.500 x .249	144	Lack of Penetration	Weld
FO	44,440	F8-3	1.500 x .249	158		Fusion Line
FO	39,050	F1-1	1.501 x .360	193		Fusion Line
FO	39,600	F1-2	1.501 x .360	180		Fusion Line
FO	36,470	F1-3	1.501 x .358	210		Fusion Line
FO	35,630	F1-4	1.501 x .359	190		Fusion Line

* Fiber Optics

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APPENDIX A CONSTANT VOLTAGE AND TRAVEL SPEED

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	SPECIMEN SIZE	VARIABLE AMPS	COMMENTS	SPECIMEN BROKE
* FO	41,410	F4-1	1.501 x .370	200		Fusion Line
FO	25,100	F4-2	1.501 x .369	180	Lack of Penetration	Fusion Line
FO	41,340	F4-3	1.501 x .369	210		Fusion Line
FO	39,520	F4-4	1.502 x .369	200		Fusion Line
FO	41,340	F7-1	1.501 x .369	195		Weld
FO	27,300	F7-2	1.501 x .361	175	Lack of Penetration	Weld
FO	38,580	F7-3	1.502 x .359	200		Fusion Line
FO	44,220	F7-4	1.502 x .357	190		Fusion Line
FO	40,210	F7-5	1.502 x .361	195		Fusion Line
TV	41,450	T1-1	1.501 x .360	190		Weld
TV	38,390	T1-2	1.502 x .359	175		Fusion Line and Weld
TV	38,760	T1-3	1.502 x .359	197		Weld
TV	40,450	T1-4	1.502 x .358	193		Fusion Line
TV	41,000	T4-1	1.501 x .359	192		Fusion Line
TV	33,310	T4-2	1.501 x .360	170		Weld
TV	39,490	T4-3	1.502 x .360	191		Fusion Line
TV	41,790	T8-1	1.502 x .368	200		Weld
TV	28,040	T8-2	1.502 x .368	180		Weld
TV	40,460	T8-3	1.502 x .367	200		Weld
TV	43,510	T9-1	1.503 x .367	201		Weld
TV	34,650	T9-2	1.502 x .367	180		Weld
TV	42,55[illegible]	T9-3	1.503 x .369	210		Fusion Line
TV	42,580	T9-4	1.502 x .369	202		Fusion Line

* Fiber Optics

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APPENDIX A CONSTANT VOLTAGE AND CURRENT

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	SPECIMEN SIZE	VARIABLE TRAVEL	COMMENTS	SPECIMEN BROKE	NOTE
TV	42,910	T2-1	1.503 x .245	60		Fusion Line	Travel - is Meter Setting
TV	43,660	T2-2	1.502 x .244	40		Fusion Line	
TV	43,480	T2-3	1.502 x .245	60		Fusion Line	
TV	41,380	T5-1	1.502 x .251	60		Fusion Line	
TV	23,890	T5-2	1.501 x .251	80	Lack of Pen	Weld	
TV	45,120	T5-3	1.501 x .251	60		Weld	
TV	42,280	T8-1	1.501 x .249	60		Weld	
TV	29,560	T8-2	1.501 x .250	75	Lack of Pen	Weld	
TV	40,106	T8-3	1.502 x .249	58		Weld	
TV	39,310	T2-1	1.501 x .361	39		Fusion Line	
TV	41,240	T2-2	1.502 x .360	50		Weld	
TV	38,580	T2-3	1.502 x .359	39		Fusion Line	
TV	39,370	T5-1	1.501 x .368	38		Fusion Line	
TV	31,750	T5-2	1.502 x .367	54		Weld	
TV	39,290	T5-3	1.502 x .366	37		Fusion Line	
TV	43,180	T10-1	1.503 x .359	38		Weld	
TV	43,730	T10-2	1.503 x .356	60		Weld	
TV	41,780	T10-3	1.502 x .357	42		Fusion Line	

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APPENDIX A CONSTANT VOLTAGE AND CURRENT

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	SPECIMEN SIZE	VARIABLE TRAVEL	COMMENTS	SPECIMEN BROKE	NOTE
FO *	40,220	F2-1	1.501 x .371	40		Fusion Line	
FO	33,760	F2-2	1.501 x. 371	50	Lack of Pen	Fusion Line	
FO	35,850	F2-3	1.501 x .367	42		Fusion Line	
FO	42,220	F5-1	1.502 x .369	38		Fusion Line	
FO	28,230	F5-2	1.502 x .368	50	Lack of Pen	Weld	
FO	40,640	F5-3	1.502 x .367	40		Fusion Line	
FO	42,720	F8-1	1.502 x .360	38		Weld	
FO	37,940	F8-2	1.502 x .358	52		Weld	
FO	43,990	F8-3	1.502 x .360	37		Fusion Line	
FO	44,740	F3-1	1.499 x .249	60		Fusion Line	
FO	38,150	F3-2	1.501 x .248	70	Lack of Pen	Weld	
FO	41,770	F3-3	1.500 x .249	60		Fusion Line	
FO	43,030	F6-1	1.500 x .251	60		Fusion Line	
FO	35,060	F6-2	1.500 x .251	80	Lack of Pen	Weld	
FO	43,570	F6-3	1.501 x .250	64		Fusion Line	
FO	43,910	F9-1	1.500 x .249	60		Fusion Line	
FO	30,650	F9-2	1.500 x .248	82	Lack of Pen	Weld	
FO	42,030	F9-3	1.500 x .249	52		Fusion Line	

* Fiber Optics

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APPENDIX A CONSTANT VOLTAGE

VIEW	ULTIMATE STRENGTH	PANEL AND SPECIMEN NUMBER	VARIABLE AMPERES AND TRAVEL	COMMENTS	SPECIMEN BROKE	VARIABLE SETTING	SPECIMEN SIZE
TV	32,020	TX1-1			Fusion Line	160 Amps 60 IPM	1.499 x .250
TV	32,950	TX1-3		Lack of Penetration	Fusion Line	150 Amps 80 IPM	1.499 x .248
TV	36,850	TX1-3			Fusion Line	170 Amps 60 IPM	1.499 x .248
TV	42,630	TX2-1			Fusion Line	160 AMPS 60 IPM	1.501 x .250
TV	32,770	TX2-2		Lack of Penetration	Fusion Line	140 AMPS 70 IPM	1.501 x .250
TV	41,740	TX2-3			Fusion Line	165 AMPS 64 IPM	1.501 x .249

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September 17, 1964 APPROVAL TM X-53131

ANALYSIS OF CLOSED CIRCUIT TELEVISION AND FIBER OPTICS FOR REMOTE VISUAL CONTROL OF TIG WELDING

By

W. A. Wall and L. K. Swaim

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This document has also been reviewed and approved for technical accuracy.

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